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ELICITATION OF VESTIBULAR SIDE EFFECTS  
BY REGIONAL VIBRATION OF THE HEAD

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Naval Aerospace Medical Research Laboratory  
Pensacola, Florida

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ELICITATION OF VESTIBULAR SIDE EFFECTS BY REGIONAL VIBRATION  
OF THE HEAD

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## SUMMARY PAGE

### THE PROBLEM

The exploitation of a fortuitous discovery that vibratory stimuli applied to the skull elicited vestibular side effects.

### FINDINGS

Vestibular side effects including visual and postural illusions, nystagmus, and motion sickness were elicited using a vibrator (held either by the subject or experimenter) applied to different regions of the head. Although a commercially available vibrator (60 Hz, 120 pulses/sec) can elicit side effects its use was enhanced by varying the vibration frequency and optimizing the stimulus conditions for perception of illusions and elicitation of motion sickness. Both horizontal and vertical nystagmus were elicited, the latter inconsistently. A strong apparent movement (and displacement) of a dimly lighted target that resembled the oculogyral illusion and apparent self-motion were consistently elicited. Motion sickness was readily elicited in some subjects but in other subjects even stimulation during rotation failed, although the period of stimulation was brief. The findings indicate that the use of vibratory stimulation should be exploited to determine whether, in addition to its use in the laboratory as a research device, it has a place in the clinic as a means of evaluating canalicular function.

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## INTRODUCTION

This report deals with the elicitation of visual and postural illusions, nystagmus, and motion sickness by applying a hand-held vibrator to different regions of the head. Insofar as we are aware there is no relevant literature on this method of producing vestibular side effects. It has long been known that motion sickness may be elicited with whole body oscillation (4, 5, 7), and recently the elicitation of postural illusions by applying a hand-held vibrator to muscle tendons has been described\* (1).

Our approach was to determine the range of vestibular side effects that could be produced by vibration, to collect systematic observations on some of them, and to leave detailed consideration of the others for future reports.

## PROCEDURE

### SUBJECTS

Table I summarizes pertinent data on the vestibular function of the six subjects who participated in one or more of the experimental procedures. No entry means the subject was not evaluated on that test.

### METHOD

#### Stimulus Conditions

Vibratory stimulation (120 pulses/second) was produced by applying a hand-held physiotherapy vibrator (Sears #663-2283) to different locations on the head. The vibrator was either held by the experimenter or by the subject himself depending on the specific procedure being evaluated. During the experiments carried out in a stationary environment, the subject was seated in a chair with his head inclined forward approximately 25°.

In some experimental series, the subject was required to fixate a visual target whose intensity could be varied, in others the subject was blindfolded or his eyes were closed; electro-oculographic (EOG) measurements of eye position were made under both of these conditions. When EOG recordings were made the vibrator tip was fitted with a non-conductive extension rod to minimize electrical interference. In other trials, the frequency of vibration was varied to determine which range was most effective and, in still other trials, attempts were made to induce symptoms of motion sickness.

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\*Dr. Guy Goodwin recommended to us the particular model of physiotherapy vibrator that we used. Our discovery of vibration-induced vestibular side effects was an offshoot of studying the proprioceptive illusions of movement that were first described by Dr. Goodwin and his colleagues.

TABLE I

Summary of Vestibular Function of the Experimental Subjects. No Entry Means the Subject Was Not Evaluated on That Procedure; the Entry "N" Signifies Normal Performance.

SUBJECT	AGE	HEALTH	NAIVE (N) SOPHISTICATED (S)	POSTURE EQUILIBRIUM	OCULAR COUNTER- ROLLING	MODIFIED HALLPIKE TEST	THERMAL CALORIC NYSTAGMUS	SUSCEPTIBILITY TO MOTION SICKNESS	
								HALLPIKE TEST	MOTION ENVIRONMENT
JL SR. AUTH.	33	V GOOD	S	N					► MED.
AG JR. AUTH.	72	GOOD	S	N	N	N	N	INSUSCEPT.	◄ MED.
CW PROF. PHARM.	53	V GOOD	S	N					◄ MED.
AL PHYS.	36	EX	N	N	N	N	N	SEVERE NAUSEA	► MED.
TT LAB. TECH.	57	EX	S	N	N	N	N	INSUSCEPT.	◄◄ MED.
JT EL. TECH.	40	EX	N	N	N	N	N	V SL.	◄ MED.

Visual Fixation. The subject was required to fixate a three-dimensional target, a box 4.5 inches x 5 inches with holes along the edges, a lamp inside the box provided illumination. The target box was positioned 8.5 feet in front of the subject and slightly below eye level. The box was tilted so that three edges were visible thus minimizing the autokinetic illusion. Target intensity was always maintained at photopic levels unless otherwise indicated and dark adaptation effects were taken into account. In some cases the target was dim, in others bright, and in still others so bright that some contours of the otherwise dark experimental chamber could be seen, and in some cases both the target and chamber lights were on. The subject was always required to report any apparent motion of the target light, giving its direction, displacement and apparent velocity. In one series of tests these estimates were facilitated by having the subject imagine the visual field as the face of a clock, with inner, middle, and outer rings. The subject could then report the direction of movement as a number on the clock dial and the extent of movement as inner, middle, or outer. In some trials, he also reported direction of any apparent motion of his body that may have occurred.

Vision Excluded. In this condition, the subject's eyes were closed or open but covered and the experimental chamber was dark. The subject was required to report any self-movement that he experienced and its direction.

Optimal Vibration Frequency. Vibratory stimuli ranging in frequency from 40-280 pulses/second were used to determine the optimal frequency for inducing apparent movement of the visual target fixated in the dark. Different frequencies were produced by driving the vibrator, which normally operates on 60 Hz, line voltage, with the amplified sine wave output of a function generator. The amplifier output was always maintained at 125 volts AC.

Motion Sickness. Attempts were made both in a stationary and in a slowly rotating room to induce motion sickness in subjects by the application of continuous vibration of two loci or alternating vibration of two loci at 120 pulses/second. The rotating environment was utilized to enhance the effect of vibration in producing vestibular side effects. During these attempts, the subjects' eyes were always closed.

## RESULTS

### VISUAL FIXATION

#### General Observations

Effective Sites. Vibration at selected sites around the ear produced illusory horizontal motion of a dim target. When attention was centered on sensations of self-rotation this illusion usually accompanied illusory visual motion. Subjects would experience themselves and the target to be turning in the same direction, although generally the target would seem to lead somewhat. These illusory motions correspond to the oculogyral illusion (2) which is dependant on stimulation of the semicircular canals. On

cessation of vibration, subjects usually reported the reverse directions of visual and self-rotation.

Vibration of the midline of the top of the skull, the forehead, or the chin (teeth clenched) produced illusory visual motion and self-movement generally confined to the "up" or "down" direction, other loci produced diagonal or oblique apparent motions. Cessation of vibration that had been applied for more than a few seconds usually produced aftereffects of opposite sign. Control trials in which the vibrator was pressed against the head but not turned on failed to produce illusory self-rotation or systematic movements of the visual target although some autokinesis was reported.

Target Intensity. Increasing the intensity of the visual target beyond that required to perceive the rows of lights always attenuated the magnitude of the visual and postural illusions. Turning on the room lights abolished illusory motion completely. The oculogyral illusion which is generally elicited by exposing subjects to angular acceleration has an extremely low threshold for perception of apparent motion in darkness but with adequate acceleration may be perceived when strong visual cues are present.

EOG Recordings. EOG recordings of eye position showed that eye movements were not essential for the illusory target motion because eye movements greater than  $1^{\circ}$  of visual angle (the approximate limit of our apparatus' resolving power) did not occur during attempted fixation.

#### Systematic Observations

Table II shows the data from three subjects which compares the apparent motion perceived for periods of 60 seconds with the vibrator applied for 30 seconds control conditions (pressure only) or stimulus conditions 180 pulses/second. For subjects JT and TT the sites of application were the left and right temple just above the zygomatic process; for AG the sites were left and right mastoid process just behind the external auditory meatus.

JT with pressure only did not report any apparent motion. In four of the six trials, the apparent movement was predominantly upward regardless of the side stimulated, reversing direction either before (one instance) or immediately after cessation of stimulation.

Subject TT perceived apparent movement, characteristic of autokinesis, under control conditions. As in the case of JT, in four of the six trials the predominant primary movement was upward and, after cessation of stimulation, downward.

For subject AG when the R mastoid was stimulated the responses were weak except in one instance when the apparent movement was rapid and to the left followed by a reversal after cessation of stimulation. Stimulation over the L mastoid resulted in a strong illusion to the left with reversal after cessation of stimulation.

TABLE II

Estimates of Apparent Motion Perceived by Three Subjects Fixating a Dimly Illuminated Target in Darkness for 60 Seconds While a Vibrator Was Applied at Pre Determined Sites on the Head for 30 Seconds; Control-Pressure Only, Vibration Stimulus 180 Pulses/Second. See Text for Details.

APPARENT MOVEMENT - DSL		SUBJECT JT											
INTENSITY	SITE	STIMULUS				TIME (SECONDS)							
		5	10	15	20	25	30	35	40	45	50	55	60
P.O.	RT	NO MOVEMENT											
P.O.	LT	NO MOVEMENT											
180	RT	3,2,I	3,2,I	6,2,M	6,2,M	6,2,M	6,2,M	6,2,M	6,2,M	6,2,M			
180	LT	12,2,I	12,3,I	12,3,M	12,3,O	12,2,O	12,2,I	6,3,I	6,2,I	7,2,I	7,2,M	8,2,M	8,2,I
P.O.	LT	NO MOVEMENT											
P.O.	RT	NO MOVEMENT											
180	LT	12,2,M	12,2,M	12,2,M	12,3,M	12,2,O	12,2,O	6,3,I	6,3,I	6,3,I	6,3,I	5,3,I	5,3,O
180	RT		12,2,I	12,2,I	11,3,I	11,3,M	11,3,O	6,2,I	6,2,I	7,2,I	7,2,M	8,2,M	7,2,M
P.O.	RT	NO MOVEMENT											
P.O.	LT	NO MOVEMENT											
180	RT	9,2,I	10,2,I	10,2,I	10,2,I	10,1,I	12,1,I	6,3,I	6,3,I	6,3,M	5,3,M	5,2,M	6,2,M
180	LT		3,3,I	3,3,I	3,3,M	3,3,M	3,2,M	2,2,I	2,2,M	12,2,M	12,2,M	11,2,M	12,2,M

		SUBJECT TT											
INTENSITY	SITE	STIMULUS				TIME (SECONDS)							
		5	10	15	20	25	30	35	40	45	50	55	60
P.O.	RT	6,1,I	6,1,I	6,1,I	6,1,I	6,1,I	6,1,I	4,1,I	1,2,I	1,2,I	1,2,I	12,2,M	12,2,M
P.O.	LT	1,1,I	12,1,I	11,1,M	11,1,M	11,1,M	10,1,M	10,1,M	9,1,I	9,1,I	9,1,I	9,1,I	9,1,I
180	RT	11,1,I	10,2,I	10,2,M	11,2,M	10,2,M	10,2,M	6,2,M	6,2,I	6,2,I	5,2,I	4,1,I	4,1,I
180	LT	2,2,I	1,1,M	1,1,M	12,1,M	12,1,M	12,1,M	8,1,M	7,2,M	7,2,I	8,2,I	8,2,I	8,1,I
P.O.	LT	6,1,I	6,1,I	6,1,M	6,1,M	6,1,I	6,1,I	7,1,I	8,2,I	8,2,I	10,2,I	10,2,I	10,3,M
P.O.	RT	4,1,I	4,1,I	4,1,M	4,1,I	4,1,I	4,1,I	5,1,M	5,1,M	5,1,M	4,1,M	12,2,I	12,2,I
180	LT	1,1,I	11,1,I	10,1,I	10,1,I	11,2,I	7,3,I	7,3,I	7,3,I	7,3,I	7,2,I	7,1,M	7,1,I
180	RT	9,3,I	9,3,I	10,3,M	10,3,M	10,3,M	10,3,M	11,3,I	1,2,M	1,2,M	1,2,M	1,2,M	1,2,M
P.O.	RT	6,1,I	6,2,I	6,2,M	5,1,M	5,1,M	5,1,M	4,1,M	4,1,M	1,1,M	1,1,M	12,2,I	12,2,I
P.O.	LT	4,1,I	4,1,I	4,1,M	4,1,M	4,1,M	3,1,M	7,1,I	7,1,I	7,1,I	7,1,I	7,1,I	8,1,I
180	RT	10,1,I	8,1,I	8,1,I	8,1,I	8,1,I	8,1,I	6,2,I	6,2,M	6,2,M	5,2,M	4,1,M	4,1,M
180	LT	2,2,I	2,2,I	1,2,M	1,2,M	12,2,M	12,2,M	8,2,I	8,2,I	8,3,I	8,3,M	8,3,M	8,2,M

		SUBJECT AG											
INTENSITY	SITE	STIMULUS				TIME (SECONDS)							
		5	10	15	20	25	30	35	40	45	50	55	60
P.O.	LM	12,1,I	12,1,I	12,1,I	12,1,I	12,1,I		9,1,I	9,1,I	1,1,I	1,1,I	1,1,I	
P.O.	RM	0,1,I	0,1,I	6,1,M	6,1,M	6,1,M	6,1,M	6,1,M	1,1,I	1,1,I	1,1,I		
180	LM	4,3,M	4,3,M	4,3,M	4,3,O	4,3,O	4,3,O	9,2,M	9,2,M	9,2,I	9,2,I		
180	RM	6,3,M	6,3,M	5,2,O				3,1,I	3,1,I	3,1,I	4,1,I		
P.O.	RM	11,1,I	11,1,I	11,2,I	11,2,I	11,2,I			6,1,M	6,1,M	6,2,O	6,1,O	
P.O.	LM	12,1,I	11,1,I	12,2,M	12,2,M								
180	RM	12,2,I	11,1,I	11,1,I	9,1,I	9,2,I	9,2,I		4,1,I	4,1,I	4,1,I	4,1,I	5,1,M
180	LM	5,4,M	5,4,M	5,4,O	5,4,O	5,4,O	5,4,O			10,1,I			
P.O.	LM	12,1,I	10,1,I	10,1,I	10,1,I	10,1,I		9,1,I	10,1,I	10,1,I			3,1,I
P.O.	RM				12,1,I	12,1,I				6,1,I	6,1,I		
180	LM	3,4,M	3,4,O	4,4,O	4,4,O	4,4,O	4,4,O	9,2,M	8,2,M	8,2,M	7,2,M	6,1,O	6,1,O
180	RM	9,3,M	9,3,M	9,3,M	8,3,M	7,3,O	7,2,M	2,2,M	3,2,M	3,2,M	3,2,M	3,2,M	3,1,O

## VISION EXCLUDED

Vibration of the same sites that had produced apparent visual displacement and self-rotation in the visual fixation condition yielded illusory self-rotation. EOG recordings of eye position showed that experienced self-rotation was accompanied by nystagmoid movements of the eyes with the slow phase in the direction opposite the change in apparent self-position.

An example of vertical nystagmus is presented in Figure 1; here the subject was experiencing upward self-movement and the slow phase of his nystagmus is "down."

Figure 2a illustrates an example of an horizontal nystagmus so generated. The subject was experiencing self-movement to the left and, as can be seen, the slow phase of his nystagmus is to the right. On cessation of vibration subjects experienced a postural aftereffect of self-rotation in the opposite direction and the nystagmoid movements of their eyes continued. However, it is notable that the direction of nystagmus did not change, i.e., the slow phase remained in the same direction as during vibration. This fact is illustrated in Figure 2b which shows nystagmus continuing after cessation of vibration for the vibration sequence illustrated in Figure 2a; it remains to be determined whether post-vibration nystagmus is ever of opposite sign.

The apparent self-rotation persisting after the end of vibration although initially in the direction opposite that during vibration sometimes would change signs after approximately a minute, occasionally more than once. This phenomenon is also characteristic of the postural aftereffect component of the oculogyral illusion when generated in the "normal" fashion.

## OPTIMAL VIBRATION FREQUENCY

Vibration at 40 pulses/second or below failed to produce apparent visual movement or self-rotation. One-hundred and twenty pulses/second, the normal operating frequency of the vibrator, produced reasonably strong illusions of motion but 180 pulses/second was the most effective stimulation frequency. Higher frequencies, 280 pulses/second (the highest that could be achieved with the apparatus), produced weaker illusions. It should be noted, however, that it is not certain that the amplitude of vibration remained constant as the frequency was varied from 40 pulses/second to 280 pulses/second. Table II presents representative data on the effectiveness of different vibration frequencies.

## MOTION SICKNESS

### Stationary Environment

In pilot-tests unrelated to inducing symptoms of motion sickness, two subjects who had been exposed off-and-on to various vibration trials for approximately an hour total

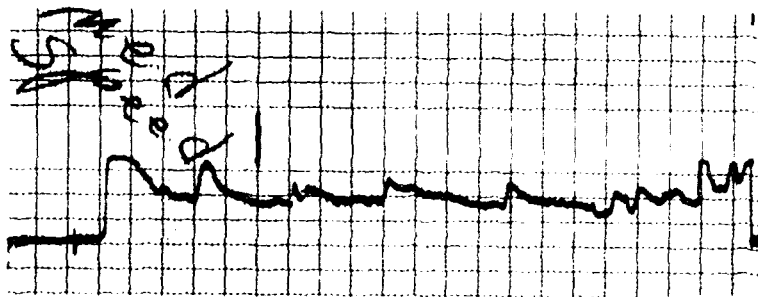


Figure 1

Record of vertical nystagmus produced by applying a physiotherapy vibrator to the top of a subject's skull just above the forehead. The slow phase of the nystagmus is down and the subject was simultaneously experiencing self-movement up. Calibration: 5 mm = 10 degrees V; paper speed 10 mm/sec.

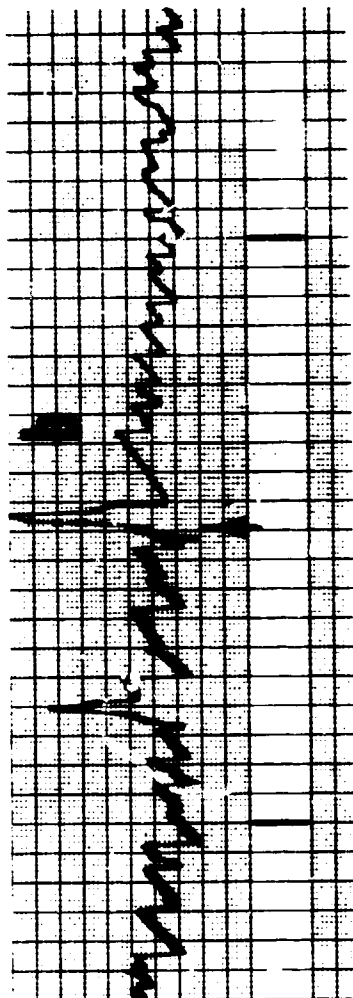
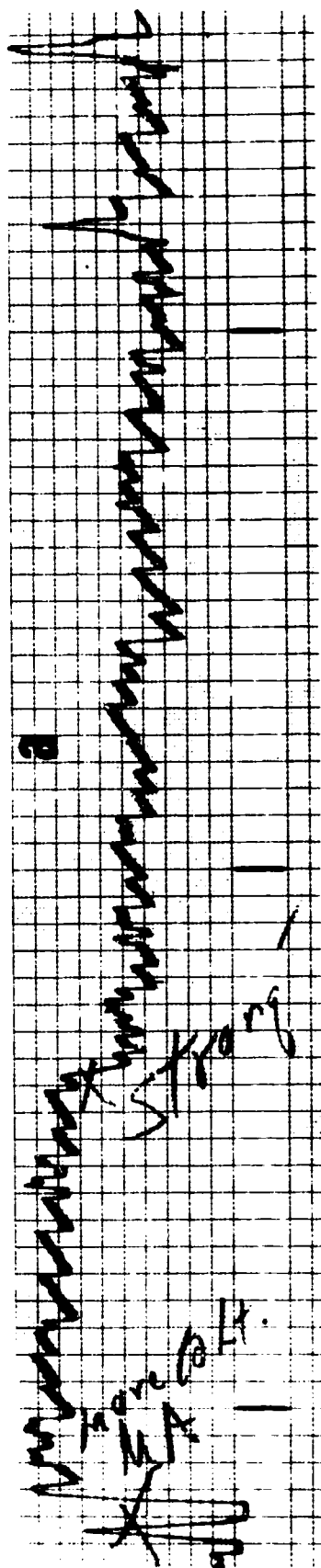


Figure 2

- a. Record of horizontal nystagmus produced by applying a physiotherapy vibrator to a subject's right cheek bone. The slow phase of the nystagmus is to the right and the subject was simultaneously experiencing self-movement to the left.
- b. Continuation of nystagmus illustrated in Figure 2a after removal of the vibrator. Arrow indicates cessation of stimulation. During vibration the subject was experiencing self-movement to the left; when the vibration was stopped he experienced self-movement to the right. His nystagmus had its slow phase to the right at all times.

Calibration: 10 mm = 10 degrees H; paper speed 10 mm/sec.

had shown slight sweating, increased salivation, stomach awareness, and dizziness (3). Dizziness following head movements had persisted for nearly an hour, although the other symptoms disappeared within a minute or two after the last vibration session.

In experimental series, continuous vibration of both occiputs (2 vibrators) for periods of 3 to 5 minutes, continuous vibration of just above each ear simultaneously or alternately for periods of 3 to 5 minutes, and simultaneous vibration of the mid-forehead and above the right ear for periods of 3 to 5 minutes, were employed. Two of the five subjects who were tested showed at most slight sweating and slightly increased salivation.

#### Rotating Environment

In a slow rotation room, bilateral stimulation of the temporal bones was carried out for 15 minutes at 6 rpm (subject AG), alternate 30 seconds stimulation of the neck at the C5 level for 5 minutes during 10 rpm rotation (subject CW); alternate 30 second stimulation of the temporal bones for 15 minutes during 10 rpm rotation (subject JL). AG and JL had their heads in an upright posture during stimulation. CW's head was inclined forward 90° and his forehead was resting on a pad. Although AG failed to exhibit any signs of motion sickness, both CW and JL showed signs and experienced symptoms. After 6 minutes of vibration CW experienced stomach awareness, which later disappeared, and slight increases in salivation and sweating; he also exhibited slight pallor which after 10 minutes developed to moderate pallor. The pallor was still present 45 minutes after the experiment when CW left for the day. JL experienced no motion sickness symptoms for the first 10 minutes of vibration; but, then he experienced stomach awareness, his salivation increased, and he felt drowsy. During the last 2 minutes of vibration, his drowsiness increased considerably and he began to experience stomach discomfort and slight dizziness and to show pallor. On cessation of vibration and return to 0 rpm, JL's stomach discomfort and dizziness increased. One hour later he was still drowsy, mildly nauseous, slightly dizzy, and salivating more than normal. Two to three hours later these symptoms still persisted in an abated form; however, movements of the head or closing of the eyes accentuated them. All signs were absent after 4 hours.

#### DISCUSSION

Our experimental observations leave little doubt that it is possible to stimulate the semicircular canals by means of a simple vibrator applied directly to the head. This new technique for stimulating the canals is of particular interest because it provides a way of stimulating the vertical as well as the horizontal canals. The visual and postural illusions that were generated by vibration of various places on the head have virtually all of the characteristics of the oculogyral illusion which normally results from stimulation of the canals through angular acceleration. Like the oculogyral illusion, eye movements are not essential for these illusions (6, 8); increases in target light

intensity and the presence of contours attenuate or eliminate them, and negative aftereffects may occur following the cessation of stimulation. Consequently, it seems that vibration can produce a pattern of canalicular stimulation similar to that produced by rotation and that gives rise to the oculogyral illusion. Although the effect of angular acceleration is bilateral, i.e., synergistic pairs of canals are involved, vibratory stimulation presumably has its direct effects unilaterally.

One difference between the aftereffects of canalicular stimulation produced by vibration and by angular acceleration should be noted. Post-rotational nystagmus is usually opposite in sign to per-rotational nystagmus, whereas the nystagmus that persists after cessation of vibration is of the same sign as that occurring during vibration. It should be noted that although post-vibrational nystagmus does not change sign, the subject feels himself rotating in the direction opposite to that which he experienced during vibration. That is, there is a dissociation between the subject's sensations of rotation and the nystagmoid movements of his eyes. Such a dissociation suggests that the mechanisms subserving subjective interpretation of ongoing body posture and the vestibulo-ocular reflex pathways are distinct and subject to independent adaptive modifications; an observation that will be the subject of further investigation.

The fact that symptoms of motion sickness could be produced using a combination of vibration and rotation provides a possible avenue for the study of experimentally induced motion sickness. This possibility as well as the possibility of using vibration as a clinical tool for evaluating canalicular function will be given the serious attention they deserve. One of the most important steps to take is to determine the actual transfer frequencies to the skull.

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